Sediment Provenance of Twin Ports Baymouth Bars

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Introduction

Minnesota and Wisconsin Points (MWP) are perhaps the most iconic landmarks in Western Lake Superior. Despite this, relatively little is known about how MWP or the neighboring Connor's and Rice's Points formed. Existing models (Kemp et al., 1978; Barlaz, 1983) call on a combination of longshore drift from the Wisconsin side of Lake Superior and sediment supply from the Nemadji and St. Louis Rivers, but none of these models can describe all observed features of the bars. Ongoing research by Mr. Swenson has led to a new conceptual model of bar formation. A fundamental component of this model involves determining the source, or provenance, of the sand that comprises these baymouth bars. To directly investigate the primary sources of sediment that comprise MWP, a sediment provenance study was conducted. A sediment provenance study is a well-established qualitative to semi-quantitative technique that attempts to determine origins of sediment bodies (the "sink") by identifying unique features or lithologies within the sediments that comprise the body and comparing them to upstream sediment sources (the "source") that could contribute those unique features (Weltje & von Eynatten, 2004). In effect, a provenance study attempts to "fingerprint" the sediment grains that make up a sedimentary feature. For example, if a sandbar is found to be 40% ilmenite, and there is a large oxide gabbro body 20 kilometers upstream, then it is likely the bar was fed primarily by sediment derived from the watershed the gabbro lies within. The manner by which this is done can include point-counting (counting each individual grain by hand) or bulk chemical analysis (x-ray fluorescence, inductively coupled mass spectrometry, or other techniques).

Minnesota and Wisconsin Points (MWP) have four potential sediment sources—the St. Louis River, which drains a large area north and west of Duluth (Fig. 2, end of paper), the Nemadji River, longshore transport of sediment derived from weathering of bedrock cliffs on the north shore of Lake Superior, and, finally, longshore transport of sediment derived from wave attack of unconsolidated glacial-till bluffs on the south shore of Lake Superior. These four potential source terranes are shown in Figure 1. Note that longshore transport on the north shore of Lake Superior is unlikely to contribute significant sediment to MWP, due to a combination of relatively low weathering and transport rates and capture of sediment 'upstream' of the Duluth canal breakwaters. In contrast, longshore transport of easily eroded bluff material on the south shore is thought to contribute substantially to MWP. The relative contributions of the St. Louis and Nemadji rivers to the modern MWP is unclear.

Figure 1: Potential sand sources for Minnesota and Wisconsin Points (MWP). Thickness of arrow shaft scales with hypothesized relative importance.

Thus, the basic goal of this study is to determine the importance of the St. Louis and Nemadji Rivers relative to south-shore bluff erosion in controlling the sand budget of the modern MWP.

Methods

Sediment was sampled from Mission Creek (a tributary to the St. Louis River), the Amnicon, Nemadji, and St. Louis rivers, and MWP (Fig. 3). At least two samples (usually three, some locations more depending on quality of sediment) of around 500 grams were taken at each sampling location and the locations of each sample were recorded in Google Maps for record keeping. The samples were then dried in an oven, sieved to extract the 1-2 mm fraction, and split equally such that the contributions from each sample bag summed to two grams.

The technique utilized in this study was adapted from an earlier technique developed by Howard C. Hobbs (1998) for tracing past glacier movement by analyzing the sediment grains that composed the till deposited by these glaciers. In the Hobbs' method, for a given till sample, the 1-2 millimeter fraction was extracted and cleaned. From this fraction, one gram (300 grains) of material is set aside to be counted under a low-power binocular scope (at least 10x). Grains were counted first by age, then by color, and finally by rock type (e.g., banded iron formation, shale, carbonate, etc.).

The technique used here keeps the spirit of Hobbs' technique but adjusts it for use in northeastern Minnesota and northwestern Wisconsin. In particular, the bedrock that would source the sediment of MP would be almost entirely Paleoproterozoic in age, which eliminates the need for sorting based on age division. Color is retained as an indicator, as this will be universally applicable, but instead of rock type, the "coarseness" (an arbitrary term taking into account weathering, size of crystals, how well crystal faces were formed, and roundedness) of the sand grain was used in lieu of sorting grains based on specific rock type. This decision was made due to time constraints, lack of rock type variety, and difficulty distinguishing rock types, but also because this acts as a proxy for distinguishing intrusive and extrusive rock.

While the decision to use such a subjective classifier may be worrisome to some, it is not a good use of time to differentiate between a granitoid that has crimson-red feldspar with black interstitial grains and individual light red to pink feldspar grains - they both would have originated from the Giants Range batholith, and thus, from the St. Louis river (Fig. 2) and can be classified as “red”. Furthermore, it can be difficult to differentiate between Fond du Lac (FdL) formation sandstone and rhyolite. While FdL sandstone can have micaceous grains and reduction spots, it is likely that one can encounter a grain with none of these useful features, and in instances like these, it is useful to be able to lump grains together as “red”.

Results

The grains counts are recorded in Table 1 and visualized in Figure 4. Potential indicator lithologies, such as Fond du Lac Formation sandstone and Thomson Formation shale, were tracked throughout the duration of this study, but were merged with the primary grain category for display here. Explanations for the sample names are included in Table 2. While sediment was collected from the Nemadji, it did not contain grain sizes desired for analysis in this study and thus is not taken into account.

Quartz grains comprise the majority of each sample with the exception of four locations: MPCP, MPBY, MCIM, and SLPB. After this, dark fine grains are present in the greatest quantities for the majority of the samples (exceptions being MPCP, MPMB, MPPP, MPBY2, ARCH, and ARSB), and after dark fine grains, red grains. After this, the greatest amount of primary grain in each sample is variable.

Discussion

The astute reader will notice an apparent contradiction in regards to the amount of sediment used in this analysis as discussed in the Results section – this is because one gram of 1-2 mm sediment only results in around 170 grains, and because of this, we doubled the amount of sediment used in our analysis to ensure accurate results.

A key component to sediment provenance is the identification of unique grains or other features – as mentioned above, it was hoped that FdL sandstone and Thomson shale would act in this regard. These hopes were dashed when grains for both lithologies were discovered in the Amnicon River sites, well away from possible transport inland from Lake Superior. Other key indicators could have been banded iron formation (BIF), but only one grain was identified that was definitely BIF. While one could assume that all magnetic rocks could be magnetite, and thus delivered by the St. Louis River, magnetite is a common accessory mineral in basalts and could have just as easily weathered out of the Chengwatana Volcanics as it could have the Duluth Complex.

After the elimination of indicator lithologies as a means of determining provenance, we had hoped that merely displaying the data in pie charts would indicate some obvious trend, such as Wisconsin Point being heavily dominated by quartz grains (lending credence to the longshore drift hypothesis), but the quartz grain counts for MPMB and MPPP are above all three of the Wisconsin Point sites, negating this hypothesis.

As a final effort, we attempted to use ratios to reveal trends in the data. If a source consistently had similar ratios, and one of the sinks ratios within the neighborhood of the source ratios, then it could be said that the source was the significant contributor of sediment to this sink. In this process, MPCP and MPBY were removed as they appeared to be man-made beaches and thus not representative of natural processes. The first of which include Equation 1, which describes the ratio of intrusive rocks over intrusive and extrusive rocks.

$$\frac{Qtz + L_{coarse} + D_{coarse}}{Qtz + L_{coarse} + D_{coarse} + L_{fine} + D_{fine}}$$

Equation 1: Calculation for deducing the ratio for intrusive rock.

In this equation, quartz, light fine, and dark fine grains are summed, forming the numerator; in the denominator, quartz, light fine, dark fine, light coarse, and dark course are summed. This ratio was computed for each location (Table 3), but most values lie between 0.49 and 0.79 with the exception of SLPB and MPPP. Next, the ratio of sandstone over the sum of sandstone and quartz (Eq. 2) was calculated (Table 4) in an attempt to use a potential indicator lithology as a means of deducing a trend.

$$\frac{FdL}{FdL + Qtz}$$

Equation 2: Calculation for deducing the ratio for sandstone and quartz.

This did not succeed, though SLSL, SLPB, and MCIM were significantly higher than the rest due to surface exposures of FdL nearby the sampling locations, but this trend is not displayed in any of the sinks. Lastly, samples from each locale were added together (for example, SLTD + SLSL + SLPB), and the primary grain type was divided by the sum of the grain types for that locale (Eq. 3). The charts for this data are displayed in Figure 5.

$$\frac{Qtz_{WPBW} + Qtz_{WPMB} + Qtz_{WPBY} + Qtz_{WPDC}}{Total_{WPBW} + Total_{WPMB} + Total_{WPBY} + Total_{WPDC}}$$

Equation 3: Calculation for deducing the primary grain ratios for each locale, in this example, for quartz.

The chart for the Amnicon River bears the most resemblance to the graphs for Minnesota and Wisconsin Points, indicating the Amnicon River is likely contributing the most sediment to MWP.

Conclusion

The Amnicon River along with south-shore longshore drift is the most likely source of the sediment comprising Minnesota and Wisconsin Points. As mentioned previously, low weathering and transport rates inhibit north-shore longshore drift sediment flux. The sediment contribution from the St. Louis River is likely “turned off” based on its difference from the Amnicon River and MWP charts due to two reasons: sediment being trapped behind the Thomson and Fond du Lac dams, and the flooding of the St. Louis estuary due to isostatic rebound (Clark et al., 1994). If the Nemadji is contributing sediment, it is too fine to be observed in this study thus its contribution can be considered negligible.

The subjectivity of the counting process is also likely a downfall of the technique used in this study. It is difficult to distinguish FdL sandstone without micaceous grains and reduction spots from slightly metamorphosed sandstone, fine-grained conglomerate, or rhyolite, so as noted above, uncertain grain compositions were lumped in with their primary grain category. Furthermore, at what point is a light grain separate from a dark grain? How grey does the grain have to be to be separated into one category vs. another? There are two potential ways further studies can eliminate this subjectivity.

Future studies may find success with two improvements to this provenance study: trace-element geochemical analysis and high resolution point-counting. Geochemical analysis would be a completely objective process and likely find success distinguishing subtle differences between the different bedrock varieties in the Twin Ports area. High-resolution point-counting is a method those short on money could utilize, where every type of grain (grey conglomerate, red conglomerate, crimson feldspar, basalt, etc.) was tracked, but this is a time-consuming process. This would require one to parse most of their samples in the manner I did to get a feel of the types of sediment, then go through and repeat the process in a detailed manner, effectively resulting in processing their samples twice over.

In summary, sediment derived from the Amnicon River and south-shore longshore drift is the most accurate model of formation for Minnesota and Wisconsin Points. If a study of this variety is attempted in the future, it should be done via trace-element geochemical analysis in a best-case scenario.

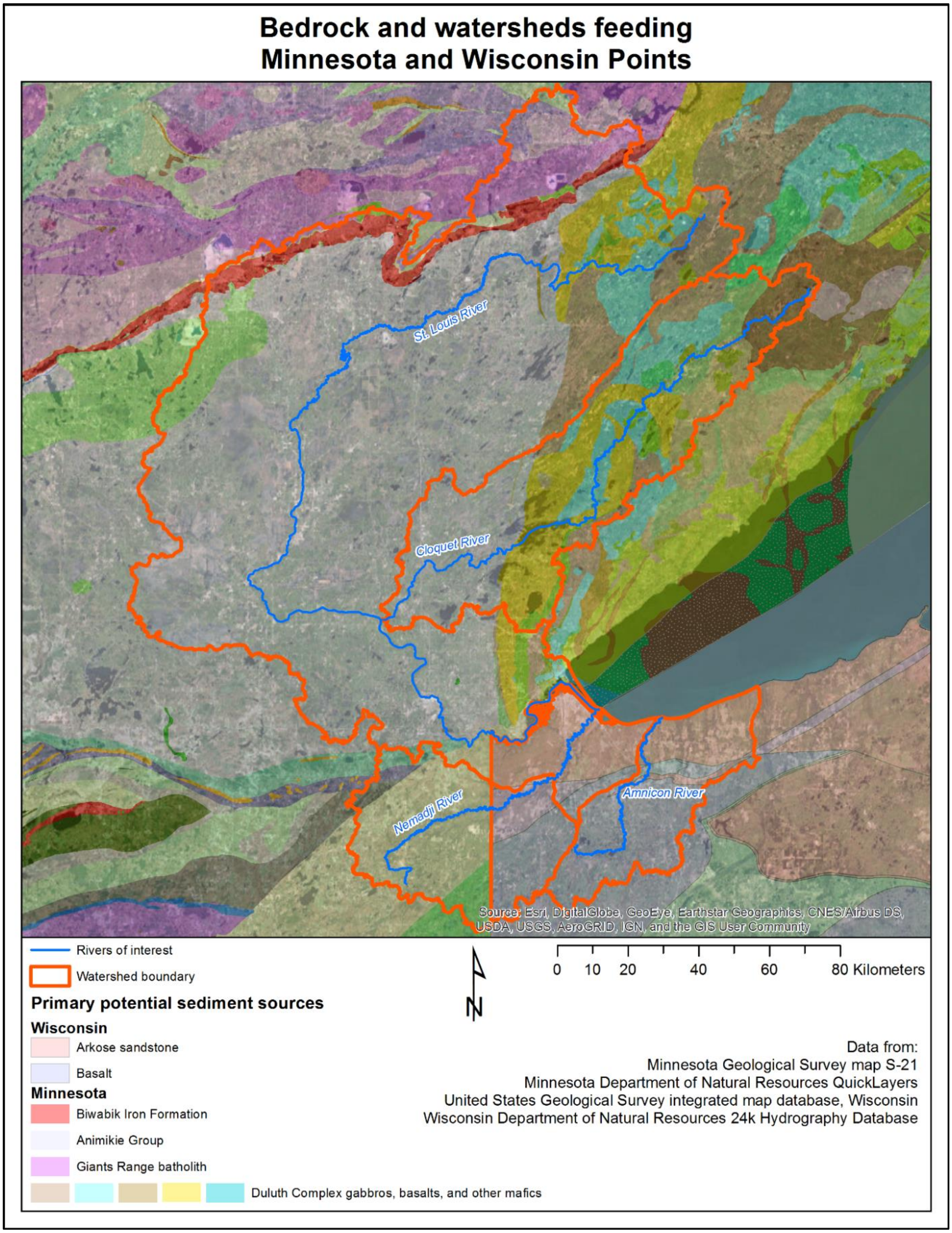

Figure 2: A map illustrating potential sediment sources for Minnesota and Wisconsin Points. It is necessarily a generalized map and does not define all potential sediment sources, only what are likely the greatest contributors. The reader will note a 50 km vertical line dividing the Nemadji watershed – this is the state border and was left in due to difficulty merging datasets. It is not actually a boundary.

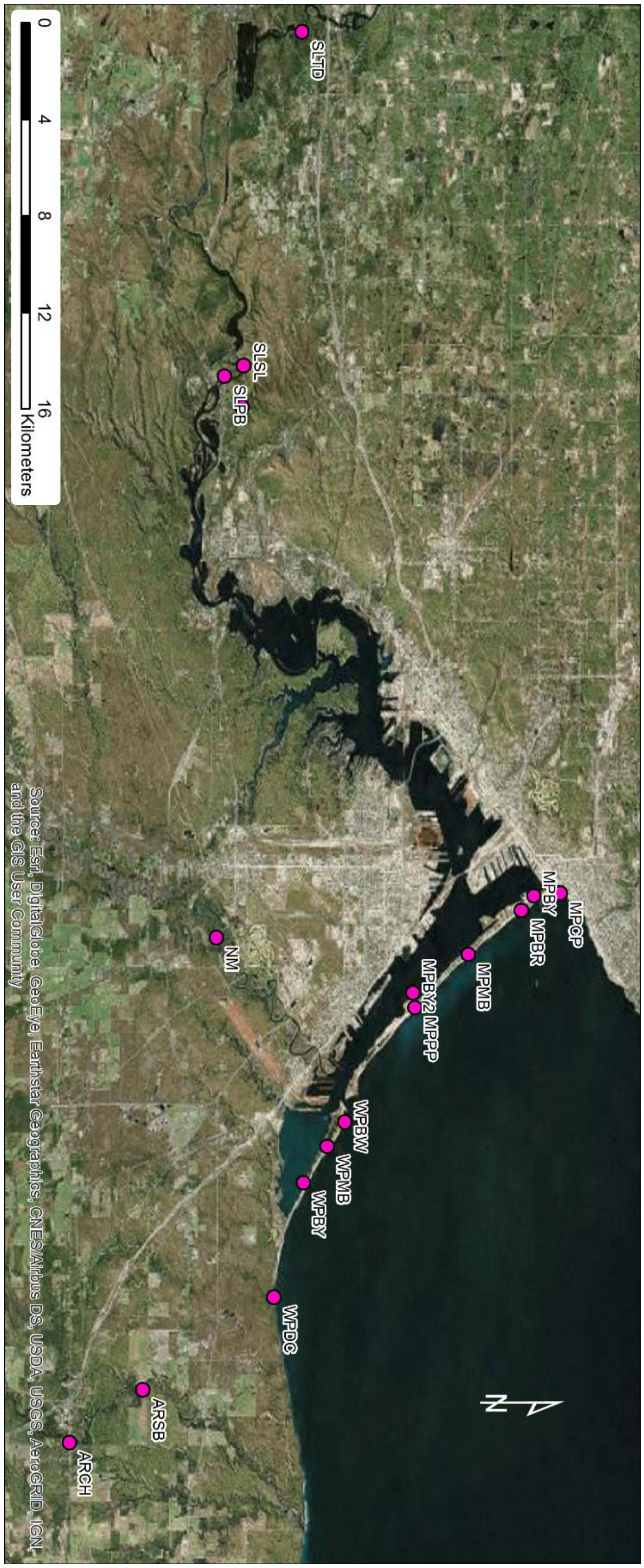

Figure 3: A map of samples taken across the Twin Ports area.

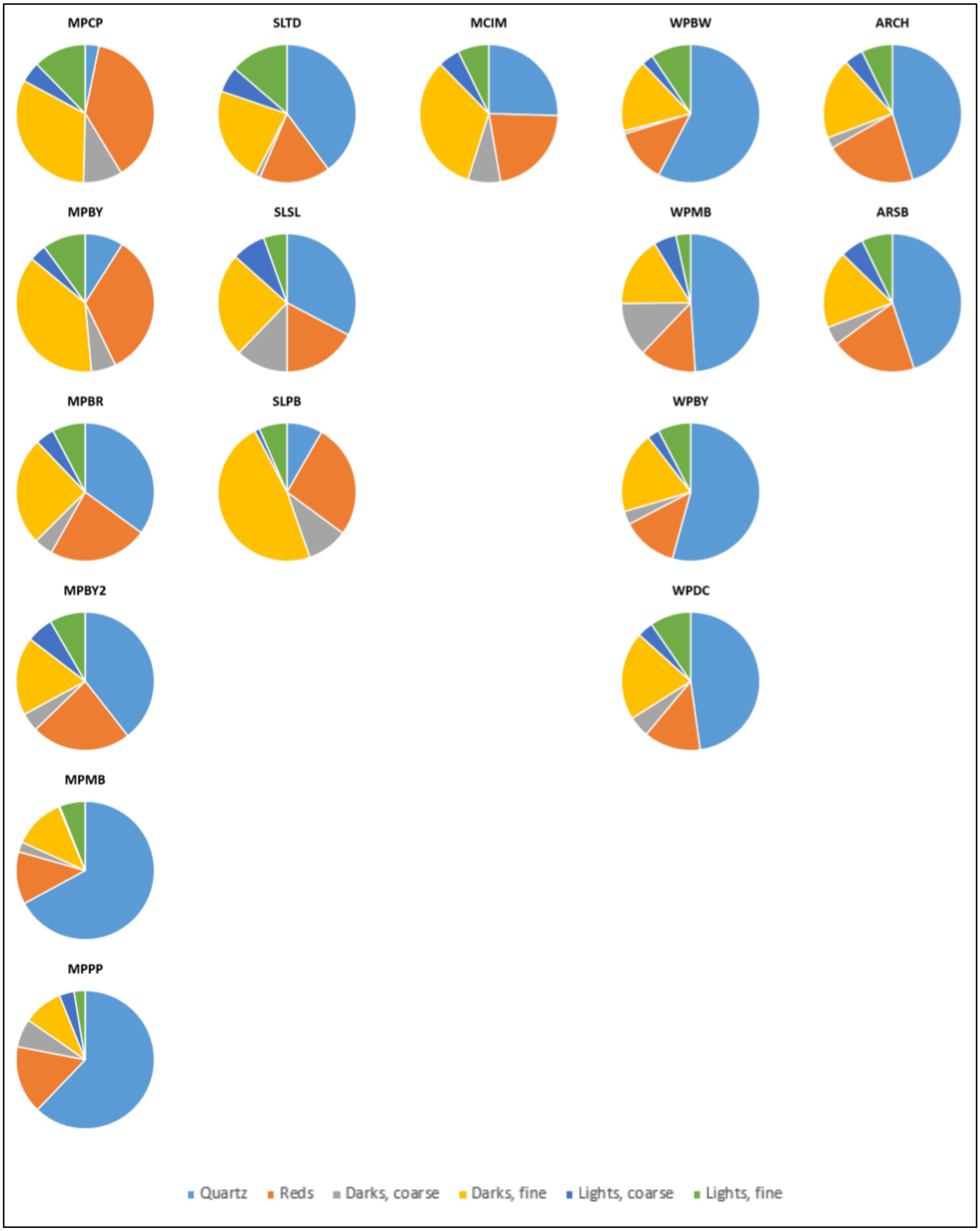

Figure 4: Visualizations of data presented in Table 1.

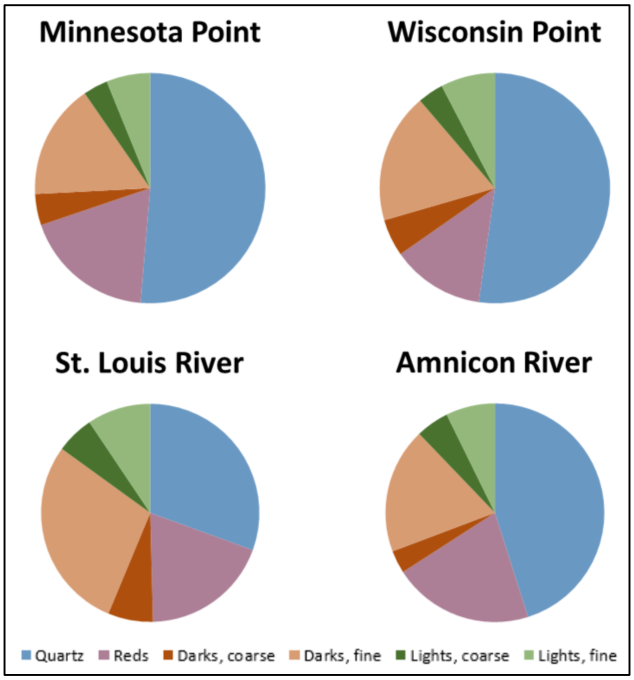

Figure 5: Cumulative ratio charts for MWP, St. Louis River, and Amnicon River.

Sample ID	Quartz	Reds	Darks, coarse	Darks, fine	Lights, coarse	Lights, fine	Total
MPCP	12	142	34	121	18	46	373
MPBY	25	94	16	104	11	28	278
MPBR	127	84	16	92	16	28	363
MPMB	257	47	9	46	1	23	383
MPPP	215	55	23	32	12	9	346
MPBY2	127	75	14	59	20	27	322
WPBW	252	55	3	74	12	41	437
WPMB	185	50	48	62	20	13	378
WPBY	191	46	11	67	10	27	352
WPDC	194	54	20	84	15	39	406
MCIM	70	60	21	90	14	20	275
SLTD	137	57	4	78	21	47	344
SLSL	83	44	31	62	20	14	254
SLPB	14	45	16	80	2	11	168
ARCH	143	68	8	60	14	23	316
ARSB	124	55	12	50	15	20	276
Total	2156	1031	286	1161	221	416	5271

Table 1: Grain counts for primary grain categories used to conduct this study. Units are in individual grains.

Sample Code	Explanation
MPCP	Minnesota Point, Canal Park
MPBY	Minnesota Point, Bayside
MPBR	Minnesota Point, Bridge
MPMB	Minnesota Point, Mid-beach
MPPP	Minnesota Point, Park Point
MPBY2	Minnesota Point, Bayside #2
WPBW	Wisconsin Point, Breakwaters
WPMB	Wisconsin Point, Mid-beach
WPBY	Wisconsin Point, Bayside
WPDC	Wisconsin Point, Dutchman Creek
MCIM	Mission Creek, Imbricated Bar
SLTD	St. Louis River, above Thomson Dam
SLSL	St. Louis River, St. Louis River
SLPB	St. Louis River, Point bar
ARCH	Amnicon River, Chengwatana Volcanics
ARSB	Amnicon River, Sandbar

Table 2: Explanation of sample codes. When used during collection, a number was placed after the first two letters to keep track of the order samples were taken.

Sample ID	Ratio, Equation 1
MPCP	-
MPBY	-
MPBR	0.57
MPMB	0.79
MPPP	0.86
MPBY2	0.65
WPBW	0.70
WPMB	0.77
WPBY	0.69
WPDC	0.65
MCIM	0.49
SLTD	0.56
SLSL	0.64
SLPB	0.26
ARCH	0.67
ARSB	0.68

Table 3: Ratios for intrusive rock.

Sample ID	Ratio, Equation 2
MPCP	-
MPBY	-
MPBR	0.03
MPMB	0.00
MPPP	0.00
MPBY2	0.02
WPBW	0.02
WPMB	0.01
WPBY	0.03
WPDC	0.06
MCIM	0.17
SLTD	0.00
SLSL	0.22
SLPB	0.13
ARCH	0.05
ARSB	0.03

Table 4: Ratios for sandstone

References

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